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Kyphoplasty Reduction of Osteoporotic Vertebral Compression Fractures: Correction of Local Kyphosis *Versus* Overall Sagittal Alignment

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Study Design. A retrospective study of patients who underwent 1–3-level kyphoplasty procedures at a single institute.

Objective. To examine and compare the effects of single and multilevel kyphoplasty procedures on local *versus* overall sagittal alignment of the spine.

Summary of Background Data. Cement augmentation has been a safe and effective method in the treatment of symptomatic vertebral compression fractures (VCFs). In addition to providing rapid pain relief, balloon tamp kyphoplasty has reduced acute fractures, allowed controlled cement placement under lower pressure, and resulted in improvement of deformity. The restoration of normal overall spinal sagittal alignment in the elderly patient with a VCF and kyphotic deformity has obvious benefits. Although significant correction of local kyphosis (fractured vertebra) has been reported in the literature, to our knowledge, there have been no reports on whether this leads to an improved overall sagittal alignment.

Methods. A total of 65 consecutive patients with symptomatic VCFs who underwent 1–3-level kyphoplasty procedures were included in the study. Preoperative and postoperative radiographs were analyzed to quantify local and overall spinal sagittal alignment correction. Preoperative and postoperative vertebral heights at the fractured levels were also measured and categorized into anterior, middle, or posterior vertebral heights.

Results. Measurements revealed that kyphoplasty reduced local kyphotic deformity at the fractured vertebra by an average of 7.3° (63% of preoperative kyphosis). This result did not translate to similar correction in overall sagittal alignment. In fact, angular correction decreased to 2.4° (20% of preoperative kyphosis at fractured level) when measured 1 level above and below. The angular correction further decreased to 1.5° and 1.0° (13% and 8% of preoperative kyphosis at fractured level), respectively, at spans of 2 and 3 levels above and below. Average height gain was highest in the middle of the vertebral body (39% increase) compared to the anterior or posterior edges (19% and 3% increases, respectively). With multilevel kyphoplasty procedures, higher angular gains were seen over more vertebrae compared to the 7.3° for a single-level kyphoplasty: 7.8° over 2 levels and 7.7° over 3 levels for 2 and 3-level kyphoplasty procedures, respectively. Kyphoplasty was able to achieve higher angular reduction in thoracic *versus* lumbar fractures (8.5 *vs.* 6.4°, $P <$ 0.01). The angular correction was also better maintained over adjacent segments in the thoracic spine.

Conclusion. The majority of kyphosis correction by kyphoplasty is limited to the vertebral body treated. The majority of height gained after kyphoplasty occurs in the midbody. Higher correction over longer spans of the spine can be achieved with multilevel kyphoplasty procedures, in proportion to the number of levels addressed. Notwithstanding its well-published clinical efficacy, it is unrealistic to expect a 1 or 2-level kyphoplasty to improve significantly the overall sagittal alignment after VCFs.

Key words: kyphoplasty, vertebral compression fracture, osteoporosis, kyphosis, sagittal alignment, fracture reduction, biomechanics. **Spine 2006;31:435–441**

Osteoporosis is considered an epidemic of the modern world. It affects approximately 28 million Americans today, and, with the aging of the baby boomers, this number is expected to increase in the near future. In the subspecialty of spine surgery, we often encounter the most common complication of this problem in the form of vertebral compression fractures (VCFs). Approximately 700,000 VCFs occur in the United States each year, approximately one third causing chronic pain.[1] In addition to the debilitating symptoms of pain that VCFs can cause, progressive loss of sagittal posture can have a tremendous impact on quality of life.[2–10] Percutaneous vertebroplasty has proven to be an effective treatment for treating the pain and preventing further collapse at the fracture level.[11–16] However, vertebroplasty "freezes" the deformity without correcting the compression, requires cement injection at higher pressures, and incurs a higher risk of cement extravasation compared to kyphoplasty.[10,17–19]

Kyphotic deformity after VCFs can potentially lead to compromise in pulmonary function, and, possibly, also gastrointestinal function, causing more than pain and postural difficulties. It has been reported that 1 thoracic VCF can cause enough overall sagittal kyphosis to cause a 9% loss of forced vital capacity.[8,20] Kyphoplasty is touted as a newer technique that allows the reduction of the sagittal alignment of the spine through the use of inflatable percutaneous balloon tamps. Height restoration and decrease of cement leakage are also argued as

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important points that differentiate this technique from vertebroplasty.[18,21,22]

The restoration of normal overall spinal sagittal alignment in the elderly patient with VCF(s) and kyphotic deformity has obvious theoretical benefits. Although significant reduction of local kyphosis (angular correction at fractured vertebra) has been reported in the literature, to our knowledge, there have been no reports on whether this leads to an improved overall sagittal alignment. Anecdotally, we have observed that in our patients, even if the fractured vertebra is reduced effectively, the overall sagittal alignment is not significantly altered by the procedure (Figure 1). The objective of this study was to examine and compare the effects of single and multilevel kyphoplasty procedures on local and overall sagittal alignment of the spine.

■ Methods

The hospital and office medical records of 65 consecutive patients who underwent kyphoplasty procedures for acute to subacute symptomatic vertebral wedge compression fractures were reviewed in this retrospective study. The fracture ages ranged from 2 to 10 weeks and were either severely disabling or persistently symptomatic, despite nonoperative treatment. Nonoperative treatment consisted of activity modification, bracing (corset), and medications (nonsteroidal anti-inflammatory drugs and other analgesics) for at least 1 week.

Magnetic resonance imaging studies were obtained and reviewed to assess for persistence edema in the fractured vertebra(e), which implies an acute or nonhealed state. The magnetic resonance imaging studies were also used to evaluate for other causes of symptoms, and ensure that the middle and posterior columns were not compromised. None of the fractures were burst-type fractures. Two surgeons using identical techniques treated all patients at a single institution, as discussed later. All were elderly patients with initial presumptive diagnoses of osteoporotic VCFs. Intraoperative bone biopsy was performed during kyphoplasty as a routine part of the procedure. After the procedure, patients with lumbar fractures were given a soft corset for comfort, to be weaned off after 2–4 weeks. Patients and their primary care physicians were also advised about aggressive medical treatment of osteoporosis or other underlying conditions if present.

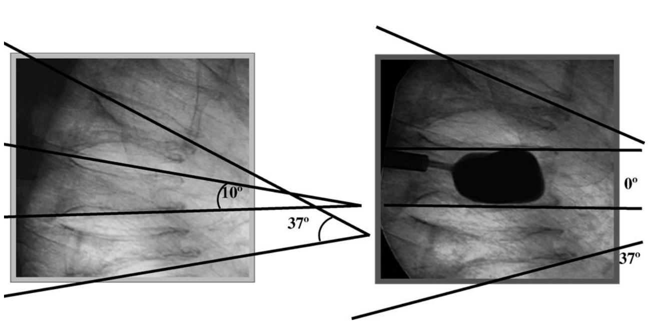

Figure 1. Many cases have been observed in which significant angular reduction produced by kyphoplasty at the level of the fracture does not translate to similar correction in spinal segments spanned by adjacent vertebrae or overall spinal sagittal alignment. For example, these figures show a VCF (left) completely reduced by the kyphoplasty balloon (right), but the kyphosis of the spanning segments stays at approximately 37 degrees.

Surgical Technique. A radiolucent Jackson table and 2 C-arm fluoroscopy machines are requested for every kyphoplasty procedure at our institute. The 2 fluoroscopy machines placed orthogonally across the radiolucent table allow simultaneous viewing of anteroposterior and lateral projections of the spine, obviating cumbersome manipulation of the machine during surgery. This process serves to speed up the operation and minimize contamination risk during the operation. The patient is then taken to the operating room, and, while on the hospital gurney, is placed under general anesthesia or monitored anesthesia care. The patient is carefully turned prone onto the Jackson table, and all bony prominences are padded well. Extreme care is taken when turning and positioning these patients because the osteoporotic and fragile nature of their bones and skin makes them easily vulnerable to fractures and skin sloughs. Two fluoroscopy machines are then wheeled into position, and the fractured level is centered in both the anteroposterior and lateral projections before the skin is prepared and the patient draped. The fluoroscopy machines are also covered with appropriate sterile covers.

Using fluoroscopic guidance, bilateral transpedicular or parapedicular access to the fractured vertebral body was obtained sequentially with trocars, guidewires, and cannulas. The Kyphon balloon tamps (Kyphon, Inc., Sunnyvale, CA) were then inserted through the cannulas and placed inside the anterior two thirds of the vertebral body on the lateral view, and covering both sides to midline on the anteroposterior view. The balloons are then slowly inflated with dye-containing fluid to reduce the compression fracture and create a void for cement injection. The inflation is performed in alternating fashion between the 2 sides, with regular fluoroscopic imaging. We choose to stop the inflation when the pressure gauge reads 220 psi or if the balloon makes contact with the endplate itself. The inflation should also be stopped if any unrecognized middle column fragment begins to displace posteriorly, although this was not observed in any of the patients in this study. The volumes of the balloons are noted. The cement is then mixed, and time is allowed to pass until it hardens to an appropriate viscosity before injection. A somewhat viscous cement mixture is less likely to extravasate through fracture lines or embolize into the local vasculature.

The balloons are then deflated and removed from the vertebral bodies and cannulas. The bone filling devices are filled with cement and then placed through the cannulas into the anterior aspect of the void created by the balloons, and the cement is injected incrementally to fill the void in retrograde fashion from anterior to posterior. As the void is filled, the bone filling devices are pulled back gradually. Regular fluoroscopic imaging is performed to ensure no extravasation occurs. Ideally, the cement stays in the anterior two thirds of the vertebral body and connects across the midline on the anteroposterior projection. The volume of cement injected is usually equal to or less than the inflation volume of the balloon tamps. The bone filling devices are then pulled back slightly but kept in until the cement hardens, then twisted to break off any connected cement to prevent cement from being left in the pedicle when pulling back to remove them and the cannulas.

Radiographic Measurements. Two unbiased surgeons (spine surgery fellows) who were not involved in the care of these patients performed all measurements. Preoperative and postoperative radiographs (*i.e.,* before hospital discharge or at first follow-up within 2 weeks) were obtained and analyzed to

Table 1. Demographics

No. Patients	65
No. single-level VCFs	46
No. thoracic (T6–T12)	21
No. lumbar (L1–L5)	25
No. 2-level VCFs	14
No. 3-level VCFs	5
Mean patient age (ys)	81
No. females	43
No. males	22
Mean body mass index	23

quantify local and overall spinal sagittal alignment correction. Anteroposterior and lateral standing radiographs were used to measure the sagittal angles. These angles were measured at the endplates of the fractured vertebra (at VCF), at the cephalad and caudad endplates of the vertebrae above and below (spanning VCF by 1 vertebra), vertebrae beyond those (spanning VCF by 2 vertebrae), and then 1 more level away (spanning VCF by 3 vertebrae). If the treated VCF was less than 3 levels away from the sacrum, the caudad measurements would stop there, whereas the cephalad vertebrae were still measured up to 3 levels away. Preoperative and postoperative vertebral heights at the fractured levels were also measured. The heights were measured at the anterior, middle, and posterior portions of the vertebral body. Moreover, statistical evaluations were performed between thoracic and lumbar VCF corrections using the *t* test for comparing mean with unknown variances.

Results

Demographics

Of the 65 patients, 43 were females and 22 were males (Table 1). Mean age was 81 years, with a range from 65 to 88. Average body mass index was 23. A total of 31 patients had single-level VCFs, 14 had 2-level fractures, and 5 had 3-level compression fractures. Of the patients with single-level VCFs, 25 had lumbar fractures and 21 had thoracic fractures (T6–T12). All fractured levels were treated with kyphoplasty through a bilateral approach. Of the 65 patients, 3 were diagnosed with myeloma based on intraoperative bone biopsy, and 62 with osteoporotic fractures based on negative biopsies. The patients with myeloma were later treated medically for their lesions, the kyphoplasty procedure having not interfered with routine treatment, and, in fact, reduced their symptoms.

Height and Angular Restoration

The kyphoplasty technique was most effective in restoring the height of the compressed vertebra in the middle region of the vertebra (Table 2). There was an average increase in mid-vertebral height by 6.4 mm, which represented a 39% increase from preoperative height. The anterior height was increased by an average of 3.1 mm, or by 15% of preoperative height. The posterior vertebral height was not changed by the kyphoplasty procedure in this patient population (0.4 mm, 2%).

Table 2. Height Restoration at VCF

	Preoperative	Postoperative	Regained
Average anterior height (mm)	20.5	23.6	15%
Average middle height (mm)	16.5	22.9	39%
Average posterior height (mm)	27.1	27.5	2%

Table 3. Angular Restoration at VCF and Spanning Spinal Segments

	Average Angular Restoration
Sagittal Angle	
At VCF (fx site)	7.3° (from 11.7° to 4.3° postoperatively)
Spanning VCF by 1 vertebra	2.4°*
Spanning VCF by 2 vertebrae	1.4°*
Spanning VCF by 3 vertebrae	1.0°*

*Net change in alignment reported. Average preoperative and postoperative angles are not reported because some segments were kyphotic and some lordotic. In addition, by convention, the negative and positive angles cancel each other when averaging.

Table 3 shows the angular correction obtained by kyphoplasty at the VCF, and at spinal segments spanned by 1, 2, and 3 levels above and below the VCF. It is noteworthy that while significant local kyphosis correction is achieved (average of 7.3°), the correction over larger spanning segments decreases with distance from the level of VCF. It reduces to 2.4° at 1 level above and below, 1.4° at 2 levels above and below, and 1.0° at 3 levels above and below.

The correction achieved with multilevel kyphoplasty procedures, in contrast to single-level kyphoplasty, is listed in Table 4. A 2-level or 3-level kyphoplasty is seen to achieve a correction similar in magnitude to a single-level kyphoplasty (7.8° and 7.7°), but over 2 and 3 levels, respectively. Thus, a larger correction is attained over a longer spinal segment in proportion to the number of levels treated with kyphoplasty. However, it is again noteworthy that the amount of angular correction diminishes when overall sagittal angular correction is measured across longer spans beyond the treated levels in even multilevel kyphoplasty. The latter 2 findings are graphically illustrated in Figure 2.

The patients were also divided into thoracic and lumbar spinal fractures groups to see if there was any difference in correction of vertebral angle, height loss, and overall sagittal alignment. The results are tabulated in Table 5. The average angular correction of a thoracic VCF was 8.5° compared to 6.4° for a lumbar VCF. Sagittal angular correction at spinal segments made up of 3,

Table 4. Multilevel Kyphoplasty and Drop-Off of Angular Correction

Kyphoplasty	Correction at VCF(s)	1 Above/ Below	2 Above/ Below	3 Above/ Below
1 Level	7.3°	33% (3)	19% (5)	14% (7)
2 Levels	7.8°	38% (4)	25% (6)	Not applicable
3 Levels	7.7°	60% (5)	40% (7)	Not applicable

Percentages reflect angular correction compared to the correction at kyphoplasty level(s). Numbers in parentheses refer to the length of spinal segment across which sagittal angular correction is measured.

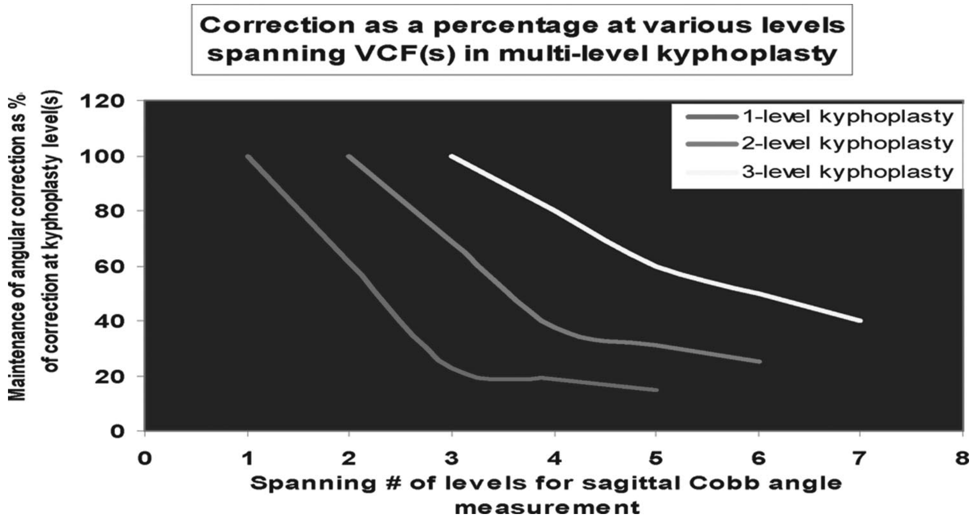

Figure 2. Graph illustrating how multilevel kyphoplasty maintains more correction over longer spinal segments, but correction still fades with distance away from corrected levels. The correction is depicted as percentage of correction of the vertebra(e) actually injected with cement.

5, and 7 vertebral levels spanning the VCF were 3.7°, 2.5°, and 1.4° for the thoracic fractures, compared to 1.3°, 0.6°, and 0.6° respectively, for the lumbar vertebrae. A higher percentage of height was regained for the thoracic VCFs, with the mid-vertebral height regained the most.

Complications

There were no significant cement extravasations during any of the kyphoplasty procedures. No cement embolizations occurred. Mild extravasation (2–3 mm) into the disc space occurred in 6 of 65 patients. The extrapolated outline of the endplate and not the extravasated cement was used during measurement of the radiographs. There was no posterior cement extravasation into the canal or foramina and no resultant adverse clinical symptoms.

Table 5. Angular and Height Correction at VCF in Thoracic *Versus* Lumbar Spine

	Average Angular Restoration		
	Thoracic Spine (n = 21)	Lumbar Spine (n = 25)	*P*
Sagittal angle			
At VCF (fx site)	8.5°	6.4°	<0.01
Spanning VCF by 1 vertebra	3.7°	1.3°	<0.01
Spanning VCF by 2 vertebrae	2.5°	0.6°	<0.01
Spanning VCF by 3 vertebrae	1.4°	0.6°	<0.01
	Height Regained		
	Thoracic Spine (n = 21)	Lumbar Spine (n = 25)	
Height measured at			
Anterior height	27%	11%	<0.01
Middle height	52%	34%	<0.01
Posterior height	3%	1%	<0.01

The *P* value was calculated using the *t* test for comparing mean with unknown variances. Power analysis revealed a power of 80% for a real difference in VCF angular correction of 2.1° between thoracic and lumbar spines.

Discussion

The amounts of height and angular correction in this study are comparable to other reported results in the literature. Height restorations of 0% to 90% (percentage of normal adjacent vertebral height) and angular corrections of 0° to 18° have been reported.[2,10,21–26] However, none of these studies comment on the effect on overall sagittal alignment. Significant pain relief is a common theme in these studies.

Biomechanically, the majority of local angular and height correction of VCFs by kyphoplasty falls within the "neutral zone" of the spine motion segment (Figure 3). In other words, the relatively softer disc material can absorb a significant proportion of the local reduction before transmitting it to the next vertebral body and changing the overall spinal alignment, which is analogous to trying to move an object by pushing against it with a cushion. The cushion will preferentially deform and absorb the load before imparting if to the object and moving it. Another reason contributing to less than com-

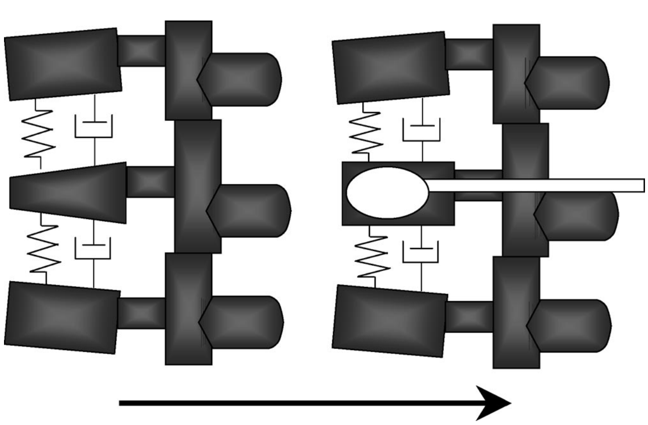

Figure 3. Schematic of kyphoplasty procedure. The intervertebral disc is a viscoelastic structure, represented by a spring and dashpot, which absorbs a significant amount of the correction imparted by balloon inflation. Thus, the local correction is largely within the neutral zone of the endplate-disc-endplate complex.

plete transmission of corrective forces through the disc is the lack of uniform loading of the endplate-disc interface.

The inflation of the balloon, by virtue of its structure or shape, does not elevate the fragmented endplate uniformly. The balloon and, later, the cement in its viscous state will follow the path of least resistance through the fracture lines, and the disc likely experiences smaller irregular areas of high load. Smaller areas of high stress are likely not as effective as uniform endplate-loading in transmitting corrective forces though the disc. Thus, although kyphoplasty can significantly increase the fractured vertebral body's height and reduce its kyphotic angle, there is often not a commensurate improvement in the spine's overall sagittal alignment. The length of the spine over which sagittal alignment is improved increases with the number of compressed vertebrae treated with kyphoplasty, but, again, the improvement diminishes when the alignment is considered using more remote untreated vertebrae.

Kyphoplasty also suffers from a low mechanical advantage when it comes to correcting global spinal sagittal alignment (Figure 4). In a kyphotic spine, the deforming moment arm of the body weight above the fracture is much higher than the corrective moment arm of the kyphoplasty balloon tamp. In a vertebral deformity model, Keller *et al*[27] suggested that a kyphotic deformity in excess of 10° at T7 and T8 produces a 15.1-cm anterior translation of the cervicothoracic spine, with an increase of 19% compressive force and 40% increase in paraspinal extensor muscle force at these levels. Consequently, a higher pressure load has to be generated by the balloon relative to the weight of the torso. However, such high loads concentrated in a small area cannot be expected to transmit through soft discs and osteoporotic vertebrae to correct global kyphosis. One must also remember that when the balloon is deflated, just before cement injection, it loses some reduction by immediate settling. Moreover, the prone position on the operating table counteracts the body weight's deforming moment, which again comes into play when the patient stands.

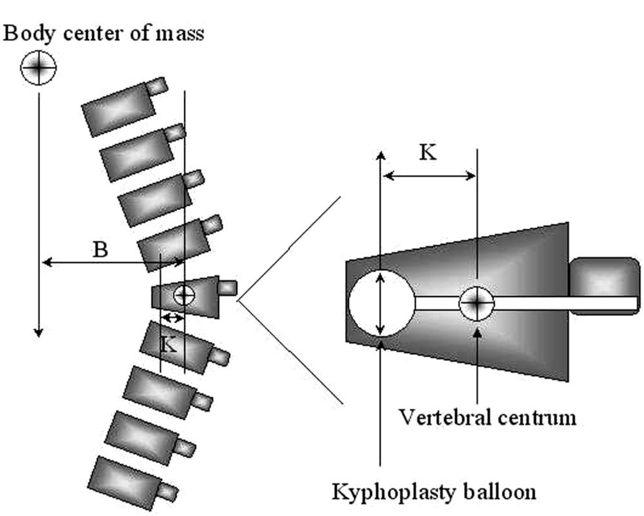

Figure 4. Schematic illustrating deforming and corrective moments around a vertebral compression fracture during kyphoplasty. The weight of the torso has a significantly longer moment arm (B) than the balloon tamp (K).

The degree of reduction of adjacent segmental alignment depends on multiple other variables, including mechanical quality of bone (density), nature of fracture (comminution), mechanical quality of disc, size of the disc (tall *vs.* bone-on-bone), number of balloon tamps, size of balloon tamp(s), placement of balloon tamp(s), age of fracture, *etc.* Soft osteoporotic bone in adjacent vertebrae cannot be pushed back as easily to correct overall alignment, the low modulus of elasticity causing the vertebra itself to deform instead. In fact, this effect may impose a risk of adjacent VCF, especially with aggressive kyphoplasty with large amounts of cement injection. There have been reports to this effect in the literature.[1,28,29]

The degree of comminution or fracture pattern is also important for determining reducibility of the vertebral height and kyphosis, because the balloon and, to a higher extent, the cement will pursue the path of least resistance through cracks. Kyphoplasty may have an advantage over vertebroplasty in this regard because the balloon tamp tends to create a void inside the vertebral body that is sealed by compacted bone. As is the case with bone, the mechanical quality of the disc also differs. Softer discs are less likely to transmit corrective forces. The quantity (height) of the disc may also play a role. A trend seen in this study was that the smaller thoracic discs tend to transmit more correction. The size and number of balloon tamps affect vertebral reduction through the area of load application and inflation height. The location of balloon placement ideally should be, if possible, where the primary compression has taken place. However, it is desirable to leave the cortices intact and avoid violating the posterior third of the vertebra to prevent posterior bone displacement or cement extravasation. The age of the VCF is an important consideration because a healed fracture is difficult to reduce.[30]

Most VCFs in this study population were of the superior endplate, and, judging by the average preoperative anterior, middle, and posterior heights, the endplates failed by compression inside the apophyseal ring into a concave configuration. Therefore, it is logical that the highest proportionate correction of height should be in the middle of the vertebral body. Also, by virtue of their placement and ellipsoid shape, the balloon tamps cause highest elevation of endplate in the middle portion of the vertebral body.

We also noticed that there was a statistically significant trend toward higher angular and height correction in the thoracic spine compared to the lumbar spine. We attribute this effect to the smaller endplates and narrower disc spaces. Although smaller balloons are used for the thoracic spine, we believe that proportionately more of the endplate is buttressed when they are inflated. There was also a statistically significant trend toward higher transmission of the angular correction to the overall spinal sagittal alignment. The thinner disc spaces of the thoracic spine are probably not able to absorb as much displacement of the endplate before transmitting the corrective load to the adjacent vertebral body. The presence of the rib cage makes the thoracic spine stiffer than the lumbar spine, also likely contributing to a wider correction of sagittal spinal curvature with kyphoplasty.

Moreover, the smaller dimensions of the thoracic vertebrae means that any gain in height is proportionately higher. The lumbar spine, which is lower, also experiences more deforming gravitational load than the thoracic spine. Nevertheless, it is difficult to interpret the statistical significance of the differences seen between these subgroups because of the difference in the architecture of each fracture. The fractures need to be carefully categorized to make the comparisons more valid.

Other techniques that may be used in conjunction with kyphoplasty to restore sagittal alignment have been described. One is to try and get as good a reduction as possible on the operating table with appropriate positioning and padding. Fluoroscopy can be used during this technique. This process will reduce the reliance on the balloon tamp for reduction of the fractured vertebra and spanning spinal segments. As discussed previously, the balloon tamp has a relatively low mechanical advantage in reducing the overall sagittal alignment of the spine, and overly aggressive balloon inflation and cementing may predispose to adjacent vertebral fracture. Heini and Orler[2] describe a method in which the vertebral bodies above and below a VCF are reinforced with cement *via* a bilateral transpedicular approach. The cannulas are left in the pedicles, and when the cement is cured, they are used as a lever to apply a lordotic moment, reducing the VCF while it undergoes cement injection. Their preliminary experience with this "lordoplasty" procedure in 30 patients yielded an average correction of 14° or 68%. Furderer *et al*[31] also described stenting of a vertebral body to correct its deformity *in vitro*.

Finally, a few words on measurement error. Many articles have been published on intraobserver and interobserver variability when it comes to measuring spinal alignment.[32–34] Certainly, this study is affected by this problem. One can clearly see the shape of the vertebral body change with balloon tamp kyphoplasty, but the effect on larger spans of the spine are smaller, as our data suggest. Carman *et al*[33] suggest that to be 95% confident that a measured difference represents a true change, the difference would have to be approximately 10° for kyphosis radiographs. However, we are not making the statement that there is significant correction of overall spinal alignment, so this problem does not work against our conclusions.

■ Conclusions

This study shows that the majority of kyphosis correction by the kyphoplasty technique is limited to the vertebra(e) treated. This limitation may be caused by elevation of primarily the fractured endplate(s) back into the disc space(s), where the soft tissues absorb the majority of the correction. It is unrealistic to expect a 1 or 2-level kyphoplasty to improve significantly overall sagittal alignment after VCFs. Multilevel kyphoplasty is more likely to affect global sagittal alignment than single-level procedures and in proportion to the number of levels treated.

■ Key Points

- Kyphoplasty is effective in partially reducing the angular deformity and regaining lost height of a VCF.
- The angular reduction attained by kyphoplasty at the level of the VCF does not translate to similar correction of overall spinal sagittal alignment.
- Multilevel (2 or 3-level) kyphoplasty is able to achieve increased kyphosis correction over the operated levels, but the effect on global sagittal alignment again decreases further away from the operated levels.

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